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THE PREDICTION OF CIVIL ENGINEERING PROBLEMS IN THE ARCTIC BY MEANS OF DUAL-CHANNEL I-R SCANNING AND AEROCHROME INFRARED PHOTOGRAPHY

Leonard A. LeSchack, et al

Development and Resources Transportation Company

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Leonard A. LeSchack, Frederick H. Morse, Wm. R. Brinley, Jr.
Nancy G. Ryan and Robert B. Ryan

Final Report and Recommendations for Advanced Research

June 1972

DEVELOPMENT AND RESOURCES TRANSPORTATION CO.

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13. ABSTRACT This is a continuation of the research reported in the Semi-Annual Technical Report #1 under the same contract. In this present report, the conclusions drawn from the research are reiterated and amplified somewhat with comparisons of single channel and product imagery, both compared with color photography of an area at which ice wedge polygons are seen on imagery but not on the photography. Since this research is clearly incomplete, the remainder of the report is devoted to detailed recommendations for advanced research to determine the utility of the dual-channel I-R scanner as an Arctic engineering tool.

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Ratio and Product Imagery - Thermal I-R						
Imagery Enhancement - Thermal I-R						
Airborne Line Scanner - Synchronous Dual Channel I-R						

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FOREWORD

This report together with the Semi-Annual Technical Report #1 of the same title dated November 1971 comprise the Final Report under the present contract. The present report is devoted to the conclusions drawn by the authors from the initial study plus detailed recommendations for advanced research to bring the dual-channel I-R technique to the point where it can become a reliable Arctic engineering tool.

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SUMMARY

This report together with the Semi-Annual Technical Report #1 of the same title dated November 1971 comprise the Final Report under the present contract. The present report is devoted to the conclusions drawn by the authors from the initial study plus detailed recommendations for advanced research to bring the dual-channel I-R technique to the point where it can become a reliable Arctic engineering tool.

The conclusions drawn are:

- Single channel I-R scanning appears to have a significant, but undeveloped potential to locate and identify massive ice in permafrost. The availability of this capability to engineers who must engage in Arctic route or site selection and construction in such areas is considered to be of value.

- Dual-channel I-R scanning appears to offer even greater capabilities of identifying such ice masses. At present, image enhancement techniques that will make the greatest use of this capability are confined to the laboratory. It is, however, preeminently feasible to adapt such capability to the field, thus giving the user vital data concerning the engineering characteristics of permafrost underlain terrain in near-real time.

- It appears that contemporary, conventional image-enhancement techniques, although satisfactory for other uses, are less suited to the identification of ice-wedge polygons in permafrost than the "ratio-product" methodology discussed by the D&RTCo.

A comprehensive program to investigate further the airborne dual-channel I-R techniques for detecting and delineating ice in the permafrost is also discussed in detail. The program items are grouped into two categories, Field Work to be accomplished during a Spring-Summer field season, and Data Reduction and Related Activities encompassing the field season; in each group they are outlined according to priority.

Field Work

(1) Obtain new and additional airborne dual-channel imagery at the Hess Creek, Shaw Creek Flats and Sourdough Sites as well as at Donneley Dome and at a North Slope area.

(2) Conduct a detailed, near surface core-drilling survey to verify the sub-surface massive ice predicted from interpretation of the imagery taken during the 1971 field season.

(3) Map the depths to permafrost at several of the above sites by means of closely-spaced permafrost probes.

(4) Obtain emissivity data of the surface cover at selected areas of the above sites. Measurements should be made in the two bandwidths used by the airborne sensor.

Data Reduction and Related Activities

(1) Continue analysis of data obtained during the 1971 field season. Air and ground-truth data, as described in the D&RTCo. First Semi-Annual Technical Report, should be appropriately analyzed prior to embarking on a new field season. These data will provide valuable guidance to new data acquisition.

(2) Continue development of a thermal model of the near-surface geology that adequately accounts for seasonal ice-water phase changes. A more reliable thermal model is required to evaluate the optimum conditions for detecting surface temperature anomalies due to massive ice in the permafrost.

(3) Develop and mathematically describe the emissivity ratio theory applied during the previous work. It was clear from that work that, although we separated to a large degree the thermal effect from that of the surface emissivity, the ratio map produced was not a simple emissivity ratio but rather a complicated function of both temperature and emissivity with the termperature effect much attenuated.

(4) Conduct an analysis of the interaction between environmental and thermal features. This should primarily be an attempt to correlate botanical micro-features on the surface with observed sub-surface thermal anomalies as well as perma-frost profiles.

(5) Examine and implement methods to electronically enhance the dual-channel I-R imagery on a near-real time basis in the field.

(6) Construct a portable semi-automatic data collection system for gathering environmental data in the field. The system used during the 1971 field season was monitored hourly by the field investigators and it was believed that this sampling rate was inadequate; the readings should be taken at intervals of approximately 10 minutes.

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1. PURPOSE OF THE RESEARCH PROGRAM

1.1 Background -- The Problem

Engineering construction in areas underlain by permanently frozen ground (permafrost) has long been a problem in the Arctic. The USSR has found this to be one of their most severe constraints in Arctic engineering construction; the United States and Canada encountered similar problems, particularly in the building of the DEWLINE stations. Currently, civil engineers are faced with route selection problems, over extensive zones of continuous and discontinuous permafrost, prior to construction of a large diameter pipeline from Prudhoe Bay to Valdez, Alaska. Military engineers will soon be faced with similar problems of route selection in support of Surface Effect Vehicle (SEV) and All-Terrain Vehicle (ATV) operations in the Arctic. In the near future, with the increasing exploitation of Alaskan mineral resources and the simultaneous requirement for causing minimum environmental damage, there is likely to be more emphasis than in the past on careful route selection.

In connection with initial surveys for the proposed oil pipeline, an extensive core-drilling program was essential to determine the engineering characteristics of the sub-surface, and the ability of the ground to support the pipeline and its associated facilities. The fact that the line was to traverse extensive regions of permafrost was known; however, the nature of the underlying permafrost was not known. As core drilling progressed, ice appeared at apparently random borehole locations as lenses, wedges, and other forms of varying thickness. It is most significant that construction in areas where permafrost has a substantial ice content is hampered due to terrain slumping as the ice responds to disruption of the thermal regime.

The problems of construction on permafrost and the research needed to solve these problems have been summarized in a recent paper in the Canadian Geotechnical Journal[1] as follows:

> "Recent interest in the practicality of transporting oil from the North has suddenly focused attention on many unsolved engineering problems related to permafrost. Fortunately, much general information is available on the occurrence and character of permafrost, but sustained research is still required on the following subjects:
>
> "1. development of remote sensing techniques for detecting permafrost in the discontinuous region, including correlations with surface features and subsurface conditions, and the properties of frozen ground, principally the ice or moisture content;
>
> "2. detailed field studies of the influence of general terrain conditions on ground temperatures and on the active layer;
>
> "3. studies of the influence of construction activities, earth fills, cuts, pipelines, and other disturbances on permafrost;
>
> "4. development of reliable probes or other convenient methods for measuring thermal properties of frozen or unfrozen soils in the field and laboratory;...."

1.2 Summary of D&RTCo. Activities in Alaska in 1971

A program was carried out in Alaska by the Development and Resources Transportation Company (D&RTCo.) in 1971 in which synchronous dual-channel I-R scanning from aircraft was used to test the feasibility of detecting massive ice in areas of discontinuous permafrost. The remote sensing techniques used appear to offer a potential solution to the problems described above and thus warrant further investigation and refinement. From the work conducted to date, these I-R techniques seem to locate and delineate areas of near surface massive ice within the permafrost without an extensive and expensive program of closely spaced core drilling.

1.3 Standard and Conventional Photo-Interpretation

The extensive literature, published in the U. S., the USSR, and Canada, shows a consensus that the phenomenon of the ice-wedge polygon is an important key to determine the presence (or absence) of massive ice in permafrost. In some areas with shallow depths to permafrost, such as coastal areas of the North Slope, conventional aerial photography clearly identifies surface polygonal structures and Aerochrome Infrared photography has also proven itself in such applications. In other areas where patterned ground is not clearly visible, conventional photographic interpretation techniques are usually insufficient to determine the presence of such ice with the degree of certainty and resolution required. A more positive method of determining such phenomena in near-real time is needed and has been the subject of the present research.

1.4 I-R Scanning in the Arctic

Based upon records of previous experiments with standard I-R scanning in the Arctic, the D&RTCo., in the Fall of 1970, proposed a potential solution to the problems described above. The majority of previous I-R work in this area employed single channel scanners. D&RTCo. proposed to use a synchronous dual-channel scanner in which two wavebands of I-R radiation could be examined simultaneously. (D&RTCo. preliminary studies conducted in late 1970 concluded that a dual-channel scanner had excellent promise as a tool by which massive ice inclusions in permafrost might be detected). Controlled field experiments to investigate the technique were conducted in Alaska during the Summer of 1971. Preliminary analysis of the data appears to substantiate the basic feasibility of the technique.[2]

2. CONCLUSIONS

The field program was concentrated at the Shaw Creek area and conclusions presented below represent a preliminary analysis of both the airborne imagery and associated ground data from that area. The work that led to these conclusions was discussed in the Semi-Annual Technical Report #1. These conclusions are illustrated in somewhat greater detail in the present report.

- Single channel I-R scanning has a significant, but undeveloped potential to locate and identify massive ice in permafrost. The availability of this capability to engineers who must engage in arctic construction in such areas is considered to be of value. Pre-dawn imagery appeared to have the greatest significant information. Polygons undetected by conventional reconaissance means, are, on the basis of these limited experiments, apparently detected by I-R scanning. The authors believe that the existence of polygons, with their associated ice-wedges, may be determined with greater confidence in areas of discontinuous permafrost or in areas where there is no visible surface expression, with the techniques described in the report.

- Dual-channel I-R scanning offers even greater capabilities of identifying such ice masses. By obtaining a product of the two signals and mapping the resultant signal, images of polygonal structures appear to be significantly enhanced. By taking a ratio of the same two signals, imagery approaching an emissivity ratio map is produced in which the temperature function is significantly attenuated. A comparison of the product and ratio maps suggests that the polygonal structures seen are thermal anomalies, and not anomalies due to surface emissivity change.

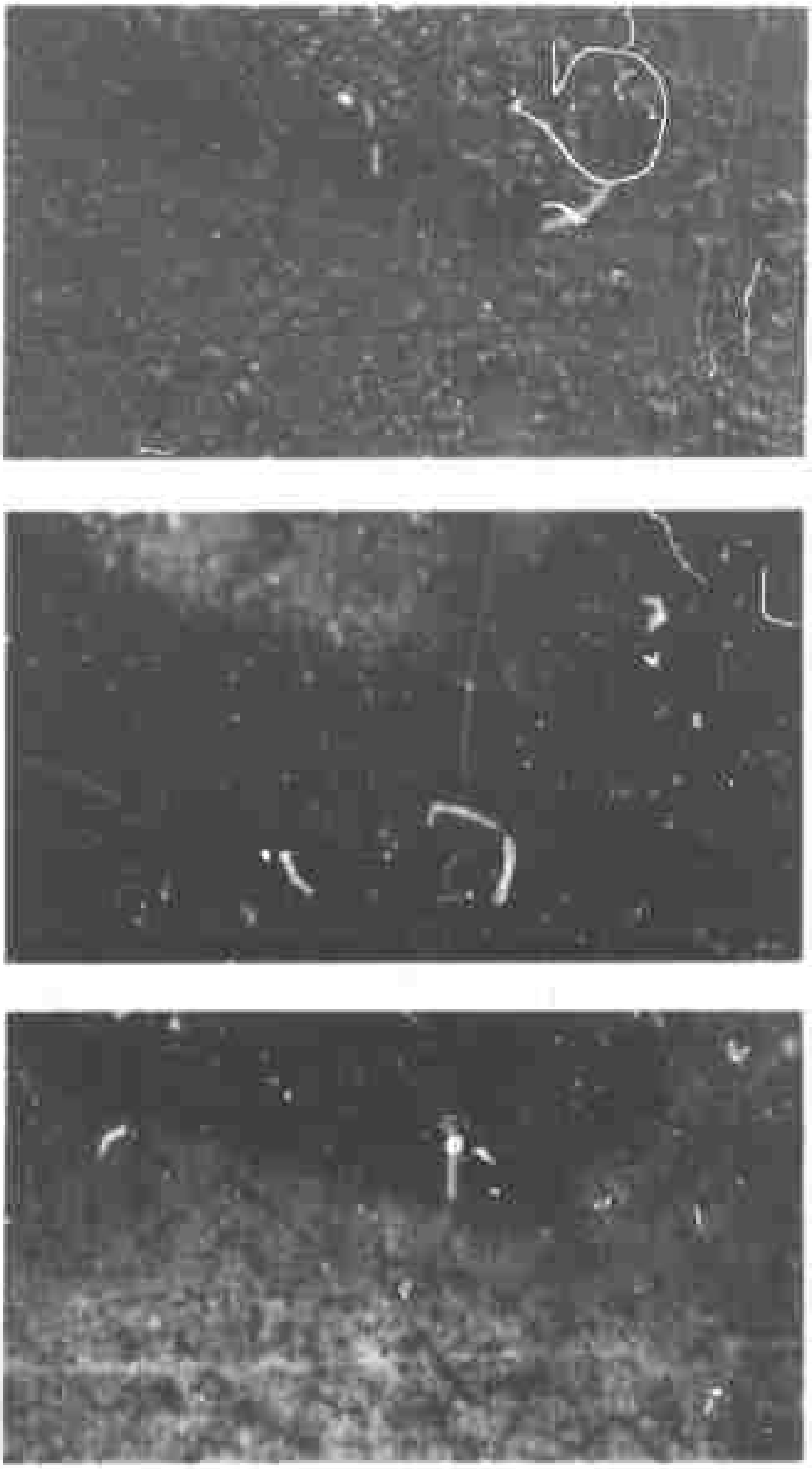
Further analysis of medium scale aerial photography indicates that a large portion of Shaw Creek Flats is composed of a series of meander scars of the Tanana River. The higher sand and gravel bars, associated with braided streams, now support spruce, larch, and poplar stands while the ancient stream channels, now silted over, support dwarf birch and willow, and sedges.

In studying both high and low altitude Aerochrome Infrared and standard color (Figure 1a) photography of the area, little or no evidence of typical ice-wedge polygon formations is discernible. Standard 8-12 micron thermal infrared imagery (Figure 1b) and D&RTCo. product imagery (Figure 1c), however, show polygonal structures in the same area.

The polygonal structures evident in the thermal imagery are located in old stream channels. These structures are believed to be surface expressions, in the form of thermal gradients, relating to near surface ice-wedge polygons similar to the reconstructed polygon in Figure 4.

D&RTCo. product imagery in the vicinity of Alyeska Test Hole TH 9-11 (Figure 2) shows enhanced polygonal structures located in an ancient stream channel. These polygons are not visible on Aerochrome Infrared photography of the area. Comparison of product imagery (Figure 3a) with single channel 8-12 micron imagery (Figure 3b) demonstrates that the former provides enhancement of polygonal structures.

The single channel imagery used in this study is quantitative and produces absolute radiometric temperature maps. Although the ratio imagery approaches an emissivity ratio map, the product signal as used by D&RTCo. is a complex quantity not as readily interpretable. Nevertheless, the product signal enhances polygonal patterns on the imagery. The reasons for the apparent enhancement of polygonal structures should be an object of further study.



(a)

(b)

(c)

FIGURE 1. (a) Low altitude vertical Kodacolor-X photograph of an area at Shaw Creek Flats, Alaska, taken on 10 September 1971 at 1600 hours (scale 1:400); (b) Standard 8-12 micron thermal imagery taken at 2200 hours on 27 August 1971 and (c) product imagery of this same site. The polygonal structures observed in (b) and very much enhanced in (c) are believed to be associated with near-surface ice wedges; these polygons are essentially invisible in (a) although careful examination of the distribution of phreatophytes (Salix spp.), seen as gray patterns in the photo, suggest the polygonal structures observed much more clearly on the product imagery.

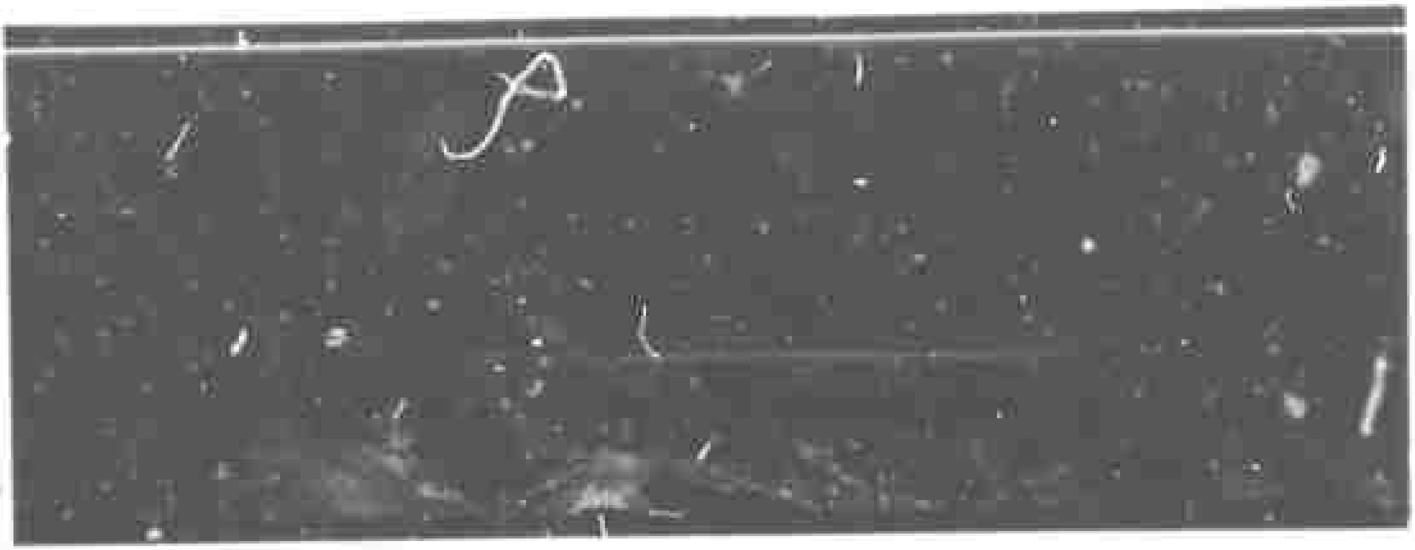
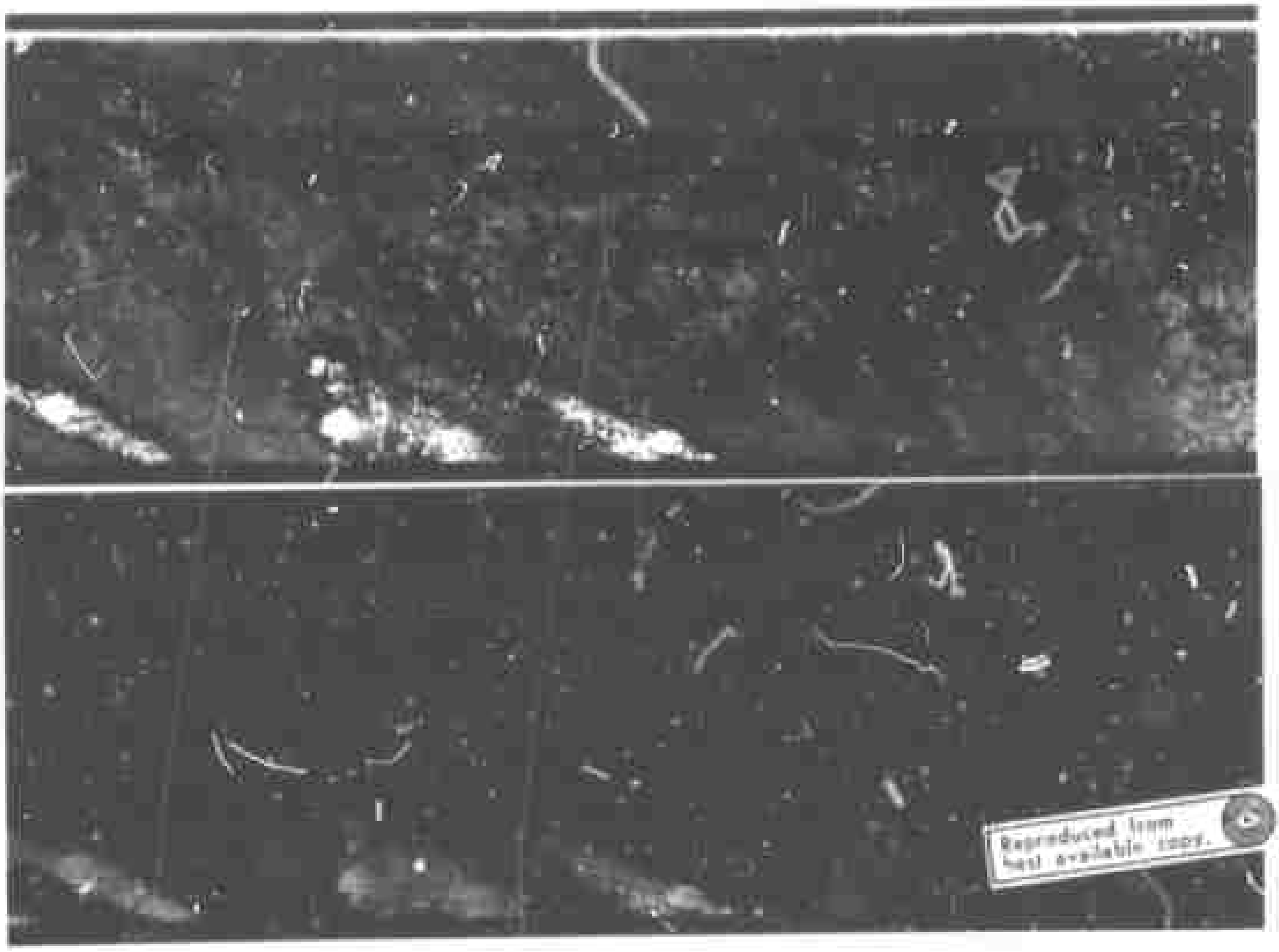


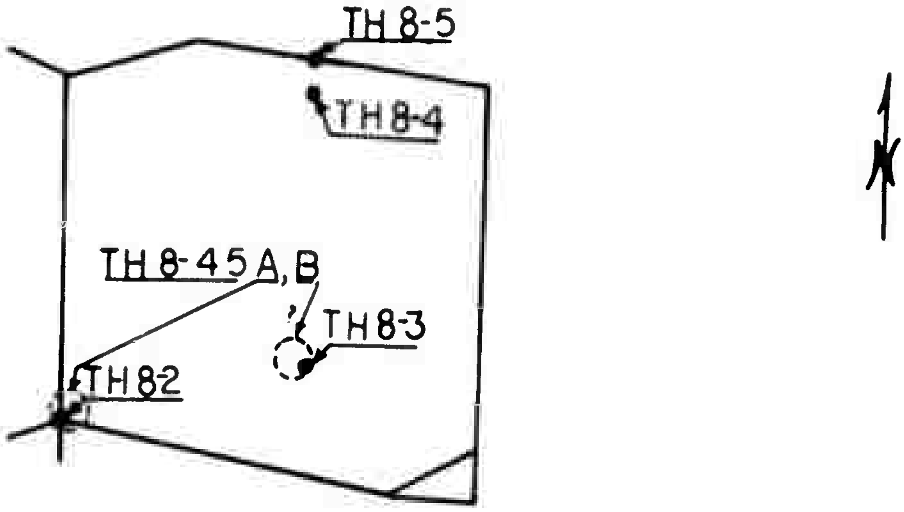
FIGURE 2 (above). Product imagery at Shaw Creek Flats, Alaska, in the vicinity of Alyeska Test Hole TH 9-11 shows enhanced polygonal structures not visible in low altitude Aerochrome Infrared photography of the same area (scale 1:2500), taken at 2200 hours on 27 August 1971.

FIGURE 3 (below). Comparison of product imagery (a) with standard 8-12 micron imagery (b) illustrates another example of the enhancement of polygonal structures achieved by the imagery multiplication process (scale 1:2500), taken at 2200 hours on 27 August 1971.

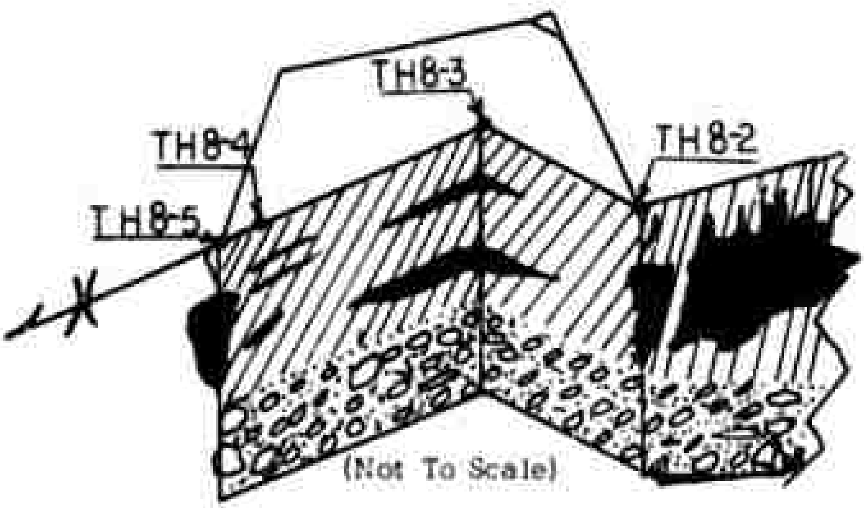


(a)

(b)



(a) POLYGON As Reconstructed From R&M Logs of Test Borings.



(b) Section Of Subsurface Structure As Suggested By R&M Logs.

FIGURE 4. A cluster of boreholes was sunk in 1970 by R & M within a visible 'freeze polygon". The polygon was reconstructed in (a) from field notes of R & M geologists. Examination of the borehole logs suggested the near-surface geologic section sketched in (b). The cores are shown in (c) opposite. It is seen that significant quantities of ice are found at the border of the polygon. This area is the center of the Shaw Creek Flats surveyed by D&RTCo.

3. RECOMMENDATIONS FOR ADVANCED RESEARCH

3.1 Field Work

3.1.1 Airborne Imagery: According to Van Lopik[3], Miller[4], as well as from the past work conducted by D&RTCo., the optimum time to obtain airborne I-R imagery which can delineate sub-surface features is during the pre-dawn hours. Additionally, all theoretical indicators point to August as the optimum month for discerning sub-surface features. The sourdough and Shaw Creek Flats Sites should be flown again, since these areas now serve as a data base and it is clearly desirable to check the repeatability of the data obtained during the 1971 field season. The Donneley Dome area (at Fort Greeley) should be overflown because fossil polygons are known to exist and have been mapped there[5] and are manifested by vegetation changes. They are "fossil" polygons because the ice that originally caused them has long since melted and been replaced by silts. Therefore, a temperature difference as significant as that sensed over ice-wedge polygons should not occur. This area, accordingly, should be overflown to test the dual-channel I-R system's ability to discriminate between polygonal patterns on the imagery associated with ice-wedge polygons and polygonal patterns on the imagery that may be caused by fossil polygons in the ground.

Close to the Shaw Creek Flats Site, but between it and the Little Salcha River, lies another area that is hilly, well vegetated, and with massive sub-surface ice that has no surface expression.[6] This Site should also be scanned.

The area at Hess Creek that was examined during the site selection survey during the 1971 field season should now be scanned in the recommended new work. Borehole data from this Site indicates some of the thickest sections of massive ice found during the pipeline survey. Examination of U. S. Geological Survey I-R data flown over this area in 1970 suggests that I-R imagery may well detect surface manifestations of this ice.

A North Slope area, lying along the proposed Alaskan pipeline route and inland, should be overflown, with flight lines being made in several directions. At least one of the flight lines should parallel a visible tractor trail. In this area, not only should the basic studies be made for determining the detectability of sub-surface ice (which is quite prevalent on the North Slope) but for determining

if this ice has preferred directional frequency of occurrence. Since trails made by vehicles traversing the tundra begin to incise themselves, with the deepest ruts occurring over massive ice (similar to beaded drainage in streams), the directional nature of the airborne study should assist in predicting best methods for utilizing airborne techniques for vehicle route selection over the tundra.

In all of the above airborne surveys, the dual-channel scanner as well as cameras with black and white and Aerochrome Infrared film should be used. Flight altitudes should be at approximately 250 m and 750 m and flights should be made at predawn as well as daylight hours.

3.1.2 Drilling Program: The near-surface drilling data obtained from several closely spaced boreholes at the Shaw Creek Flats Site permitted the preparation of a profile of the near-surface geology showing the distribution of massive ice (Figure 4). These boreholes, made as part of the survey for the proposed Trans-Alaska Pipeline, were rarely close enough together to permit the study of this sub-surface ice distribution and how it is associated with the polygonal patterns detected with airborne I-R imagery. It is clear, however, that the ice predicted from the interpretation of this imagery should be verified by a detailed survey of the sub-surface. Boreholes should be sunk at selected locations at both the Shaw Creek Flats Site and the Sourdough Sites. (See Figure 5).

It is recommended that at each Site, 50 boreholes should be sunk to a depth of approximately 3 m with a grid spacing of 2 m. Plotting the sub-surface distribution of massive ice based on data obtained from such closely-packed grids should permit more realistic evaluations of the ability to predict sub-surface ice from airborne I-R imagery. In addition, it is recommended that the actual temperature anomalies associated with the massive ice within the grid areas be measured with thermistor arrays.

3.1.3. Permafrost Mapping: Measurements of depth to permafrost, obtained by means of a metal probe pushed through the thawed ground to the permafrost surface, should be conducted on a grid pattern as was done during the 1971 field season. The depth to the hard surface encountered, i.e., the isothermal frozen layer, should reflect near-surface concentrations of massive ice due to the difference in thermal diffusivity of this ice and the surrounding permafrost. These permafrost-probe grids should be made at each of the Sites studied

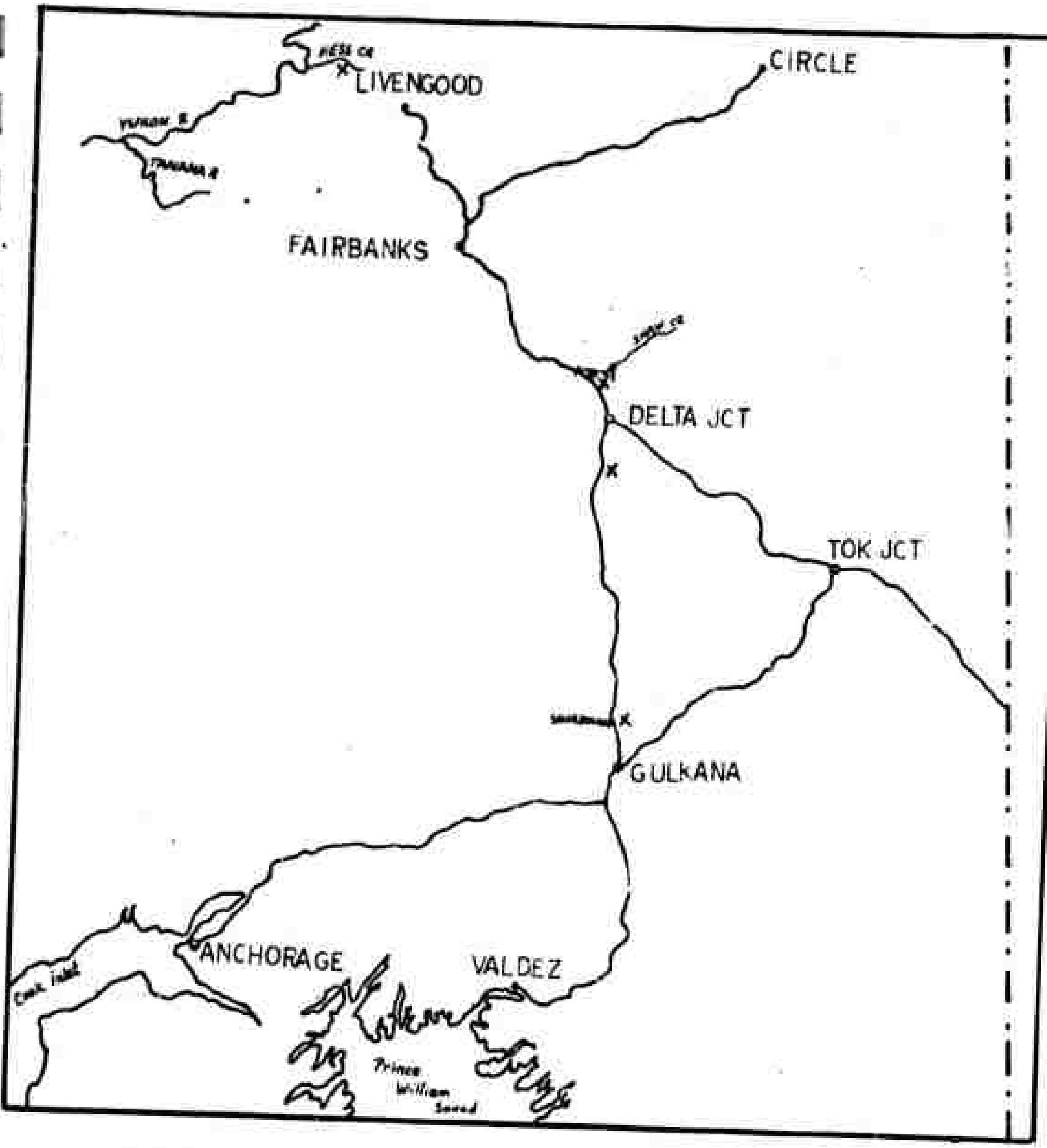


FIGURE 5. Map of Anchorage-Fairbanks areas showing study sites south of the Brooks Range.

and should include within them the borehole grids discussed above; this would permit correlation of major irregularities of the permafrost surface with massive ice inclusions in the permafrost below. To facilitate reducing all probe measurements to a common datum, the graduated probe should be read by means of sighting through a surveyor's level. Simultaneous measurements of the surface topography should also be made so that thickness of the active layer from place to place can be computed.

3.1.4. Emissivity Data: During the past studies, published emissivity data tabulated for typical substances, reasonably similar to those that were measured, were used in the basic calculations. These emissivity values are generally obtained by an instrument that integrates wavelength-dependent radiances over a large I-R wave-band which may or may not be valid for studies using specific narrow band-widths. The authors therefore suggest measurement in situ of the emissivity, as a function of wavelength, of the terrestrial surface encountered in the field survey, over the 3-14 micron I-R band. Emissivity measurements have been made in the past[7,8] using field-type equipment. The resulting spectral emissivity data could be used for the determination of the optimum wave-bands for the dual-channel scanner and as an aid for interpreting ratio imagery as well as other forms of processed imagery.

3.2. Data Reduction and Related Activities

3.2.1. Data Gathering: The data gathered during the 1971 field season were as follows:

- Dual-channel I-R imagery
- Aerochrome Infrared and Black and White photography
- Surveyed ground control
- Portable radiometer transects
- Meteorological measurements
- Thermistor array temperature profiles
- Vegetation transects
- Permafrost profiles

Additional data to be obtained during the recommended advanced research should include:

- Thermal properties of near surface layers
- Spectral emissivity of terrestrial surfaces
- Solar radiation
- Borehole data

All of the data obtained during the ground truth studies are related to the patterns visible on the I-R imagery. The ground truth data should be correlated with the airborne data for aiding and verifying imagery interpretation. Additionally, these ground truth data should be used for input to the thermal model being developed as well as for verification of predicted surface temperatures.

3.2.2. Thermal Model: During the pre-field phase of the present work (see reference 2) the annual variation of surface temperature for several typical geological near-surface sections, subject to known meteorological conditions, was computed using the University of Michigan thermal modeling computer program.[9] While this program both adequately represents the multilayer nature of the near-surface geological section and accounts for the significant modes of energy transfer across the surface, the energy required for or released by the phase change processes, i.e., melting and freezing, cannot be properly accounted for. It is therefore recommended that during annual research studies a new thermal modeling computer program be assembled from various available one-dimensional heat flow models, one which contains a boundary condition at the moving phase change surface. This boundary condition would account for the phase change energy. In addition, the influence of micro-topography and vegetation cover on the energy transfer rates at the surface should be analyzed. The resulting thermal modeling program should first be used to predict both the temperature profiles and the depth of the active layer in the multi-layer sections found at several of the CRREL ground temperature sites.[10] Upon successful completion of this test, the thermal modeling program should then be used to determine the magnitude of the surface temperature difference for pairs of near-surface sections, identical except for a layer of ice in one section. The thermal model would also permit the evaluation of the optimum conditions for detecting thermal variations due to massive ice within the permafrost.

3.2.3. <u>I-R Signal Ratio Theory</u>: The authors have been depending, to a large degree, on the capability of delineating thermal effects from emissivity effects by obtaining the ratio of the signals produced simultaneously by the dual-channel scanner. The ratio signal so produced is a highly complex function that, although clearly appearing to accomplish the delineation that was sought, must be thoroughly examined analytically before one can be certain of what is actually mapped. The ratio of the signals, although approaching an emissivity ratio, still has lesser order temperature functions associated with it. By analytically describing this signal and then cancelling out these undesirable temperature functions, a map more closely representing an emissivity ratio map can be produced. The approach and logic that is recommended to accomplish this is outlined below.

The total spectral radiance received by either of the I-R detectors is the sum of the following terms:

- the spectral radiance of the ground surface
- the spectral radiance of the sky incident on and reflected by the ground surface
- the spectral radiance from the emission of the atmosphere in the path between the detector and the ground surface.

The first two terms are each modified by the atmospheric transmissivity, and all three terms are then modified by the spectral response of the detector filter. A final modification by the spectral response characteristics of the detector itself yields the detector output signal which essentially represents the imagery. Using the Daedalus quantitative synchronous dual-channel I-R scanner, the output signals of two detectors, each operating in a different portion of the I-R wavelength spectrum, are synchronously recorded on magnetic tape. The purpose of using two detectors is to provide sufficient data so that the emissivity changes of the terrestrial surface can essentially be separated from temperature changes of the surface. With such a separation of emissivity changes from temperature changes, the thermal anomalies due to massive ice within the permafrost can be confidently identified.

Since the complete analytical separation of emissivity changes from temperature changes is prevented by the complexity of the radiance terms described above, the separation of emissivity

changes from temperature changes by a limiting technique is suggested to assist in providing a realistic analytical description of the ratio signals. With the development of such a technique, imagery pattern changes due primarily to emissivity changes could be distinguished from imagery pattern changes due primarily to temperature changes. In this suggested method, two ratio signals would be formed; namely, a temperature change ratio signal (TCRS) and an emissivity change ratio signal (ECRS). The former is identical to the ratio signal used in the present study, while the latter represents a suggested new function.

(a) TCRS -- this ratio signal will identify pattern changes due primarily to temperature changes. The ratio of the two detector output signals will be formed. Regions that have a uniform tone in the imagery (Figure 6a) may be examined relative to single channel imagery (Figure 6b). Patterns appearing on single channel imagery, yet not appearing in the ratio imagery, are due primarily to temperature changes.

(b) ECRS -- this ratio signal would identify imagery patterns due primarily to emissivity changes. Using the internal temperature calibration of the scanner and/or measured ground temperatures, the spectral radiance of a black body at the ground temperature over each wave-band would be computed. In each wave-band, the detector output signal would be divided by the black body radiance, point by point, and the ratio of the resulting signals (in each wave-band) would be formed. Regions that appear uniform on this imagery (Figure 6c) would be compared to the same regions on the single channel imagery (Figure 6b). Patterns appearing on the single channel imagery, yet not appearing on this ratio imagery, should be due essentially to emissivity changes.

Figure 6d shows the corrected map indicating patterns essentially due to temperature changes only. The analytical development of the theory of these two limiting ratios should provide the basis upon which the accuracy of the separation of emissivity changes from temperature changes can be determined.

In addition to developing the above ratio technique, the spectral emissivity data obtained from the recommended field work (see section 3.1.4) should be used to determine the optimum wave-bands for the ratio technique.

3.2.4. Botanical Studies: In inland Alaska, in zones of continuous and discontinuous permafrost, ice-wedge polygons seldom show surface expression with changes of vegetation such as is found

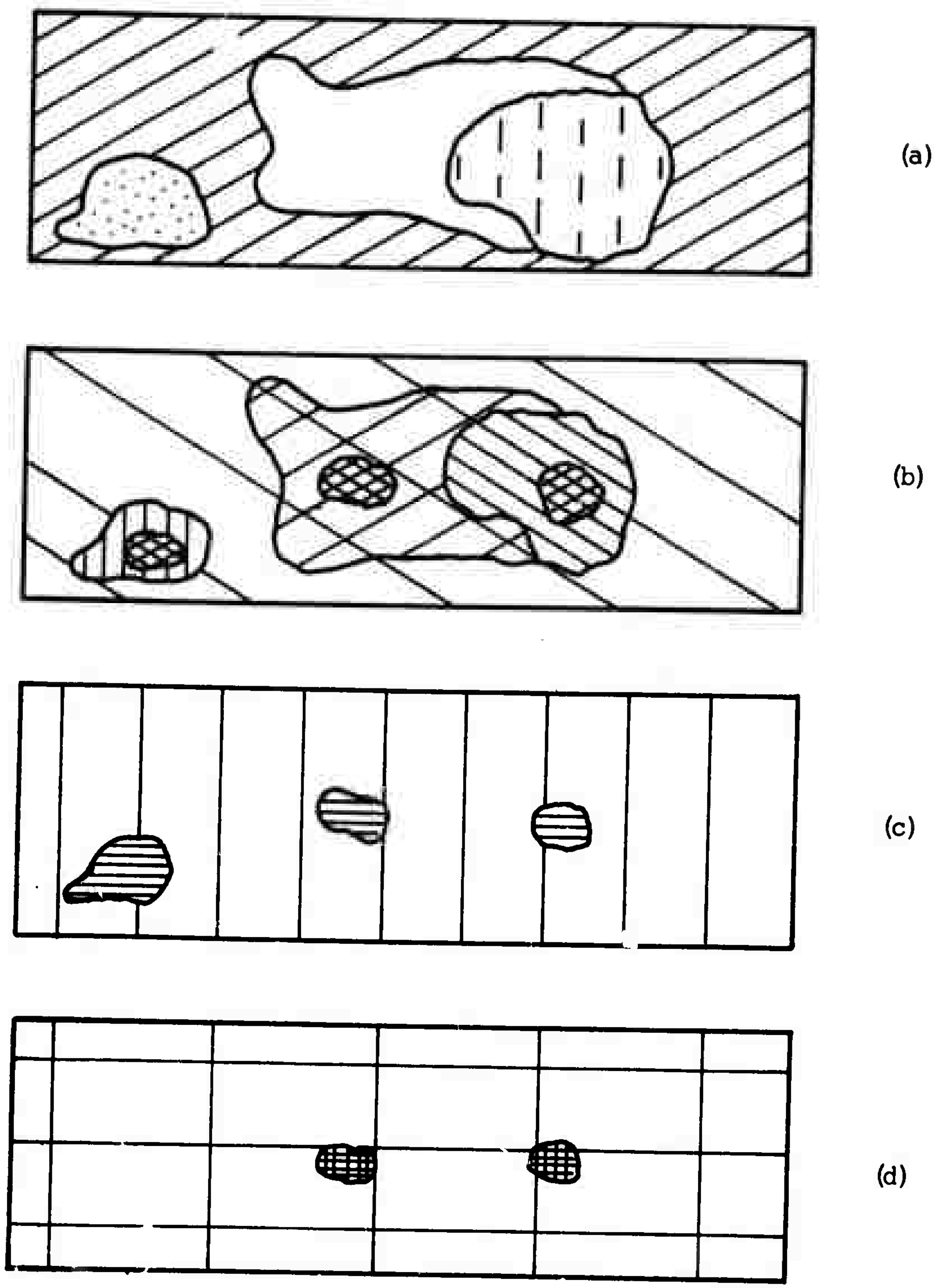


FIGURE 6. Conceptual illustration of maps produced by: (a) temperature change ratio signal (TCRS), (b) single channel imagery, (c) emissivity change ratio signal (ECRS), (d) corrected map showing only true temperature changes.

along the coast of the North Slope. Aerochrome Infrared photographs of U.S.G.S. origin (August 1970) and D&RTCo. origin (August 1971) verify this. The authors recommend, however, additional photographic studies which may lead to the ability to predict areas of ice-rich silt and massive ice inclusions, although without actually being able to delineate the ice structures. Also recommended is Aerochrome Infrared and Aerocolor photography over the same test areas and phenotypical studies to determine the ability of the vegetation in early spring to reflect near-surface ice concentrations. Ground truth studies concurrent with a drilling program could map the micro and macro-botanical features of the traverses.

3.2.5. Imagery Enhancement: Muoh has been published about electronic enhancement of multi-spectral imagery and many enhancement techniques are now in common usage. Enhancement systems range from simple filters and level slicing to digital computers performing sophisticated mathematical operations on the raw imagery data. From work conducted to date by D&RTCo., the authors have concluded that simple filter systems, level slicing, and complex factor analysis such as described by Carnes and Hanson[11] appear to be of marginal value for enhancement of the thermal anomalies of interest to this study. The greatest potential for image enhancement of interest appears to be in the application of product imagery, and ratio imagery (see section 3.2.3) similar to that described by Vincent et al.[12], Vincent and Thomson[13] and in the first Semi-Annual Technical Report on this project. A simple, hybrid (analog-digital) system seems to be the most efficient means for producing the desired enhanced imagery. In simulated analysis, this system appears to show promise in differentiating anomalies due to the presence of sub-surface ice. Additionally, the hardware for this system is compact and has the potential for being installed aboard aircraft for use in real time by means of a C-scan presentation.

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